UTILITY PATENT APPLICATION

TITLE OF INVENTION: **SYSTEM AND METHOD FOR DRAINING SOIL PROFILES**

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TITLE OF THE INVENTION

SYSTEM AND METHOD FOR DRAINING SOIL PROFILES

CROSS - REFERENCE TO RELATED APPLICATIONS

This patent application claims the benefit of U.S. Provisional Patent Application Serial No. 60/446,368 filed on 02/10/2003 and entitled "System for Draining Soil Profiles," the disclosure of which is incorporated as if fully rewritten herein.

STATEMENT REGARDING FEDERALLY FUNDED RESEARCH

This invention was not made by an agency of the United States Government nor under contract with an agency of the United States Government.

TECHNICAL FIELD OF THE INVENTION

The present invention relates generally to systems and methods for treating soil, and more specifically to a system and method for draining excess water from soil profiles in areas such as golf courses and other commercial properties.

BACKGROUND OF THE INVENTION

Turfgrass areas, such as those on golf courses, are typically subjected to moderate to heavy foot traffic on a daily or weekly basis. Excessive water retention in such areas is highly undesirable due to the damage that may occur as a result of foot traffic and other factors. Thus, turfgrass areas are reconstructed to include some drainage capability. The soil profile of such areas is commonly constructed as an excavation into the soil native to the site. A high sand content root zone and frequently coarse sand or fine gravel sub-layers are subsequently placed within this excavation. Subsurface drainage from this essentially closed basin is necessary and is typically provided by drainage pipe spaced from three (3) to six (6) meters apart and placed in shallow trenches in the subgrade soil. One example of such a turf soil profile is that used in putting greens by the United States Golf Association ("USGA").

Depending on the availability of suitable root zone and gravel materials, a putting green soil profile typically consists of a 300 mm thick, high sand content root zone mix positioned above a minimally 100 mm thick, specified but predominately fine gravel zone. The gravel rests on the subgrade soil except when adjacent to drain line trenches, where the

same gravel also fills the trench. The particle size distribution of the gravel typically conforms to engineering specifications for a drainage filter. Such conformity helps to ensure maintenance of layer integrity and suitable hydraulic performance of the gravel.

During and shortly after rainfall, the gravel layer of a USGA putting green promotes rapid drainage of the root zone. This occurs because excess water exiting the root zone follows a nearly vertical path, thereby employing the maximum extent of the gravitational gradient. Furthermore, the maximal distance drainage water must travel to exit the root zone is virtually the root zone depth, or 300 mm. Lateral flow to the spaced apart drainage elements occurs mostly within the very high permeability gravel layer. The gravel drainage blanket beneath the finer textured root zone also creates a large difference in the pore size distribution across this interface. This large separation of predominate pore sizes within these adjacent media yields a capillary break in the vertical direction. Consequently, the lower portions of the root zone remain saturated (or nearly so) after drainage has virtually ceased. Depending on the particle sizes of the root zone and gravel materials used for a given installation, the thickness of this perched water zone may vary. For coarser root zone and finer gravel textures, a thinner perched water zone will form and the upper surface of the capillary fringe will still reside at sufficient depth to ensure adequate air-filled porosity near the soil surface. For finer root zone and coarser gravel textures, the perched water zone will be quite thick and may severely reduce the proportion of air-filled pores near the soil surface.

Surface slopes, such as those found on putting greens and athletic fields, also occur on or at the interfaces between soil layers within the profile. This is because profile layers are typically built to a uniform thickness across the green or field. When the interface between layers is well defined, and there is a wide disparity between soil textures of adjacent layers, the accumulation of water is subject to interflow. This down-slope movement of subsurface water is particularly evident in profiles with high permeability root zone media and greater root zone depths. Presumably, only a high permeability root zone would allow sufficient rates of interflow for the modest slopes of these systems. Also, a deeper profile depth would provide a greater reservoir of soil water available for such flow. Consequently, the perched water of a USGA green would in time migrate down slope resulting in lower soil water contents at higher elevation locations and higher water contents at lower elevation locations across the field or green.

This phenomena results in the need for localized hand watering of high elevation locations within some putting greens, a costly and time consuming operation. Thus, it is evident that a high sand content root zone placed over a gravel layer provides rapid drainage during and shortly after a rainstorm. However, after this rapid drainage phase has ended, perched water that is retained in the root zone results localized soil wetness and laterally non-uniform soil water contents across naturally contoured putting greens and athletic fields.

The prior art includes technologies that address the perched water problem. Commercial applications of this technology typically consist of using air pumps or blowers to apply a sub-atmospheric pressure within the gravel layer. The vacuum thus helps remove the excess, perched water. This, however, is an active process requiring motor driven blowers and functions only during such times that the vacuum is applied. Thus, there is a need for a system that effectively removes, excess perched water, but that is passive, requires no human or mechanical intervention, and that continues to function as long as excess water is present in the soil profile.

SUMMARY OF THE INVENTION

These and other deficiencies of the prior art are overcome by the present invention, the exemplary embodiment of which provides a passive system and method for effectively removing excess water or other fluid from a soil profile. An exemplary embodiment of the system includes an array of fibrous capillary drains inserted at regular intervals into the soil profile. These capillary drains traverse one of more of the layers of the soil profile. Typically, the soil profile in question includes a root zone and a gravel layer beneath the root zone, and the capillary drains provide a continuous porous pathway of capillary pores extending from the lower reaches of the root zone through the gravel layer. The capillary drains themselves may be constructed from fiberglass rope, fiberglass tape, or a contained column of sand or similar particulate matter.

The exemplary general method of the present invention for draining excess fluid, i.e., water, from a layered soil profile, includes the steps of removing a sample of the layered soil profile, separating the individual layers of the soil profile, determining the particle size of the layers, determining the water retention properties of the layers based on the particle size; and inserting a plurality of fibrous capillary drains at regular intervals into the soil profile such

that the fibrous capillary drains traverse one of more of the layers of the soil profile. Typically, the capillary drains are permanently placed within the soil profile and are not removed. Thus, the capillary drains provide ongoing, passive removal of undesired water for as long as the drains remain in the soil profile.

Further advantages of the present invention will become apparent to those of ordinary skill in the art upon reading and understanding the following detailed description of the preferred embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated into and form a part of the specification, schematically illustrate one or more exemplary embodiments of the invention and, together with the general description given above and detailed description of the preferred embodiments given below, serve to explain the principles of the invention.

FIG. 1 is three-dimensional graphic representation of the array of the capillary drains of the present invention inserted into a soil profile.

FIG. 2 illustrates a preferred placement of the passive capillary drains of the present invention within the soil profile to be drained.

FIG. 3 is a graphic representation of the pattern of the passive capillary drainage drawdown within an area treated with the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention provides a system and method for implementing passive capillary drainage of turf soil profiles. The system of this invention includes an array of spaced-apart, fibrous capillary drains that are installed within a layered, turf soil profile. Preferably, these capillary drains are oriented vertically and span from the sub-grade soil surface to about 100 mm into the lower portions of the root zone (see FIGS. 1 and 2). These capillary drains provide a continuous pathway of capillary pores from the lower reaches of the root zone and through the gravel layer, thus eliminating the capillary break present in layered soils. Preferably, the fibrous capillary drains of this invention have a small diameter

(c.a. < 1 inch) so that installation will minimally disrupt the existing system. In an exemplary embodiment, the capillary drains are spaced-apart (c.a. 2 feet) as to not inhibit the lateral flow characteristics of the gravel layer. Furthermore, the fibrous nature of the capillary drains permits the drains to maintain their physical integrity within the gravel layer when lateral flow conditions exist. Finally, these capillary drains have a sufficient flow capacity to allow timely removal of the perched water.

The exemplary general method of the present invention for draining excess fluid, i.e., water, from a layered soil profile, includes the steps of removing a sample of the layered soil profile, separating the individual layers of the soil profile, determining the particle size of the layers, determining the water retention properties of the layers based on the particle size; and inserting a plurality of fibrous capillary drains at regular intervals into the soil profile such that the fibrous capillary drains traverse one of more of the layers of the soil profile. Typically, the capillary drains are permanently placed within the soil profile and are not removed.

For analyzing a root zone / sand layer type soil profile, a soil-coring tool is used to withdraw a sample of the profile and visually inspect it to ensure that the soil is appropriately layered and that the root zone material is sandy throughout. A small sample of the root zone is removed from the coring tool for closer visual examination to ensure that the particles fall within an expected size range. The water retention properties of the root zone are inferred using basic soil physics principles (see Example 1), and from visual inspection of the particle sizes. Because many turf root zones are sufficiently similar, a single material, e.g., fiberglass rope will perform adequately in most situations.

In an exemplary embodiment, fiberglass rope is utilized for constructing the capillary drains of the present invention. The water retention and hydraulic conductivity properties of some commercially available fiberglass ropes, as well as the use of fiberglass as a passive capillary sampler of soil, is known in the art. Ropes ranging in diameter from about 0.25 to 1 inch (0.64 to 2.54 cm) have been shown in the scientific literature to have water retention and conductance characteristics compatible with the method of the present invention.

To effectively and efficiently remove the perched water in a layered soil profile, a passive capillary drain of the present invention typically includes a distribution of pore sizes

that are compatible with the root zone so as to provide a continuous, porous pathway spanning the gravel layer. If the majority of pores in a capillary drain are substantially larger than the root zone, then a capillary break would likely occur at the interface between the capillary drain and the root zone, thereby disrupting this pathway. However, if the pores of a drain were substantially smaller that the root zone, then presumably the drain would have insufficient hydraulic conductivity to convey flow in a predictable and efficient fashion.

In the case of a wettable medium such as fiberglass, or a root zone soil, the water retention properties directly relate to the pore-size distribution characteristic of the respective materials. Furthermore, the water retention properties can be conveniently described by a set of parameters values derived where the parameter values result from a fit of the equation to water retention data of the respective porous medium. A single index, H_m, can be calculated from the curve parameters where H_m is the inflection point of the curve and physically represents the hydraulic head value at which the majority of the pores become air-filled or, in other words, drain.

The two examples provided below demonstrate the effectiveness of the present invention at draining excess water from root zone over gravel soil profiles. Example 1 provides experimental data that demonstrates that the material selected to act as the capillary drain has adequate flow capacity (expressed in volume per time units) to drain a given volume of soil within 24 hours. Example 2 demonstrates that the water removal, after 24 hours, was uniform throughout the soil volume. In general, the following examples support the application of passive capillary drainage system of the present invention for use in layered putting green or athletic field soils. The data and calculations included demonstrate the effectiveness and efficiency of this invention and indicate that the use of such calculations is an appropriate and effective means for simulating hydrologic processes occurring in the field.

EXAMPLE 1

Table 1, below, provides the water retention curve coefficients (i) of two grades of fiberglass, and (ii) of various root zone mixes. Comparison of the H_m parameter values indicates excellent compatibility between the pores sizes of fiberglass rope and those of the root zone mixes. In general, the H_m values for the fiberglass rope are slightly more negative than comparable values for the root zone mixes. This indicates that the larger pore sizes of

the fiberglass rope will drain at a slightly greater soil water suction than the root zone with which it is in contact. Thus, the majority of the pores in a fiberglass rope will remain water-filled and able to conduct flow, as the majority of pores in the root zone drain.

Table 1. Water Retention Curve Coefficients of Fiberglass Rope and Root Zone Mixes

Sample	α	n	M	H_m
	cm^{-1}			cm
Fiberglass rope†				
AM 3/8 Hi	0.013	2.31	0.77	-66.4
AM 3/8 Md	0.024	2.76	0.51	-32.6
AM 3/8 Lo	0.025	2.03	0.83	-37.3
AM 1	0.024	1.44	1.25	-49.3
PEP 3/8	0.028	2.72	0.97	-35.1
PEP ½	0.055	3.61	0.40	-14.1
Root zone mix				
Sand	0.036	4.54	0.78	-26.4
Sand/sphagnum	0.036	4.00	0.75	-25.7
Sand/reed sedge	0.030	6.35	0.84	-32.2
Sand/compost	0.041	3.16	0.68	-21.8
Sand/muck peat	0.032	5.33	0.81	-29.7

† Sample names for fiberglass rope are from Knutson and Selker, *Soil Sci. Soc. Am. J.* 58:721-729 (1994). Values are the nominal diameter (inches) of the rope.

The present invention utilizes a soil water suction equal to 10 cm (4 in) of water when using fiberglass rope as a passive capillary drain, since according to the drain configuration, a 10 cm suction would be expected to occur where the capillary drain intersects the root zone material. Table 2 below gives hydraulic conductivity, K, and flow capacity, Q, values for the fiberglass rope sample. Information for both a single or double strand of rope is included since either could be used for a particular application.

Table 2. Hydraulic Conductivity and Flow Capacity Values for Fiberglass Rope

Strands	Product	Cross-section area†	K at 10 cm suction	Q at 10 cm suction
		cm	cm h^{-1}	cm^3 h^{-1}
1.				
2.Single	AM 3/8 Lo	0.99	265	262
	AM 3/8 Md	0.74	238	176
	AM 3/8 Hi	0.88	171	150
	AM 1 Md	6.74	295	1990
	PEP 3/8	0.60	354	212

	PEP ½	1.65	438	723
Double	AM 3/8 Lo	1.98	265	525
	AM 3/8 Md	1.48	238	352
	AM 3/8 Hi	1.76	171	300
	AM 1 Md	13.5	295	3980
	PEP 3/8	1.20	354	425
	PEP ½	3.30	438	1450

† From Knutson and Selker (1994).

Flow capacity values are the product of the hydraulic conductivity and cross sectional area of passive capillary drains. These values give the volume of water per unit time that is conducted through a capillary drain under a unit hydraulic gradient as would occur in a vertically orientation installation. Flow capacity for single strands range from 150 to nearly 2000 cm^3 h^{-1}, and doubling the number of strands will typically increase the flow capacity two-fold. Thus, a wide range of flow capacity values exist due to the diversity of fiberglass rope materials that are commercially available. A simple calculation demonstrates that these Q values are sufficient to efficiently remove perched water from a layered soil containing a sandy root zone.

Consider a USGA putting green soil profile where it is desired to lower the capillary fringe by 10 cm (4 inch, or one-third of the total root zone depth) within a 24-hour period. Based on water retention measurements of typical USGA root zones, the specific yield of this media calculated as 0.30. Thus it is desired to remove 3.0 cm^3 of water per cm^2 soil area in a 24-hour period. Using the flow capacity of fiberglass rope given in the previous table, one can estimate the total water volume that can be removed by a single passive capillary drain (consisting of either a single or double strand or rope) in a 24-hour period. Operationally, this estimation is simply Q x 24 h. Considering the desired quantity of water removal with the 24-hour capacity of the capillary drain, it is possible to calculate the surface area of a green that would be served by a single capillary drain. In the case of a capillary drain, installed as described in above, and having a flow capacity of 200 cm^3 h^{-1}, this area is 1.7 ft^2. If the capillary drain had a flow capacity of 1000 cm^3 h^{-1} the area would be 8.6 ft^2, and for a flow capacity of 2000 cm^3 h^{-1} the area would be 17.2 ft^2.

By way of example, installing passive capillary drains in a uniformly spaced grid across a section of a putting green spaces these drains at 1.3, 2.9, or 4.1 feet for flow

capacities of 200, 1000, or 2000 $cm^2 h^{-1}$, respectively. Such an installation represents an acceptable configuration, as the spacing is wide enough to avoid disrupting to the existing surface, the later flow path in the gravel, and the soil media itself.

While the calculation above provides an estimation of root zone drainage using a passive capillary approach, this method assumes that all drainage water within the zone of influence of a capillary drain would be readily accessible for removal through the capillary system. If this were not the case, then the lowering of the capillary fringe would likely be non-uniform, with greater drawdown in the vicinity of the capillary drain and very little drawdown at further distances. Indeed, if there were a large difference in the level of the capillary fringe with distance from a drain, then this would indicate that the root zone was incapable of readily supplying water to the drainage element and flow rates would be less than required. Thus, a second embodiment of the present invention is directed toward lowering the capillary fringe uniformly across the area in question.

EXAMPLE 2

A second example of the system of the present invention comprises a uniformly spaced grid of passive capillary drains placed within a USGA putting green. Calculation of the drawdown across an area within this grid can be accomplished by representing this system as a well field with uniformly spaced wells. Whereas wells extract water upward with flow driven by pumping, the capillary drainage elements extract water downward into the gravel with flow driven by gravity and limited by the flow capacity of the capillary material. However, in both cases, the flow to a well or drain is radial and through the surrounding porous media so that calculation of drawdown uniformity may be described the same for both systems.

In this example, a multiple well solution for a confined aquifer and for each well fully penetrating the aquifer is employed. Use of a confined aquifer solution when, in fact, the system is unconfined is appropriate provided the drawdown is less than the aquifer thickness. Also, the passive capillary drains of this disclosure do not fully penetrate the root zone, but rather penetrate one-third of the total depth. However, according to the equation below, a fully penetrating well solution represents a reasonable approximation of the actual configuration:

$$s(r,t) = Q\,(4\pi T)^{-1}\,[W(u_1) + W(u_2) + \ldots]$$

$$u = r_i S/(4Tt_i),\text{ and } W(u) = -0.577216 - \ln u + u - u^2/(2\ 2!) + u^3/(3\ 3!) - u^4/(4\ 4!) + \ldots$$

Where $s(r,t)$ is the drawdown as a function of distance from a well, r, and time, t; Q is the flow capacity; T is the transmissivity of the root zone (a product of the hydraulic conductivity and height of the capillary fringe); and S is the specific yield of the root zone.

In this example, the above equation was solved for square array of 121 capillary drains that were evenly spaced at 0.61 m. The flow capacity of the capillary drain was 500 $cm^3\ h^{-1}$. The specific yield and hydraulic conductivity of the root zone were 0.3 and 20 $cm\ h^{-1}$ (8 in h^{-1}), respectively. This example presumes that the capillary fringe extends to the ground surface (30 cm height), a situation much in need of drainage; and that this level will drop approximately 10 cm over the 24-hour time period of the calculation. Thus, the height of the capillary fringe for calculation purposes was chosen as 25 cm. This yields a transmissivity of 500 $cm^2\ h^{-1}$. Finally, the results were generated for the immediate vicinity of the central capillary drain of the total array. Presumably, this represents the entire area of a putting green since at the edge of a green an essentially impermeable boundary would occur where the root zone interfaced with the native soil, and the principal of images would typically apply.

With reference to FIG. 2, the drawdown after a 24-hour period is shown as a contour plot. The central capillary drain is assigned the coordinate values of 0,0. The eight adjacent capillary drains are located on the edge of the solution area. The mean drawdown from 117 solutions of the problem was 8.74 cm with a standard deviation of 0.06. Thus, as shown in FIG. 2, the drawdown is very uniform, deviating by about 1 mm across the simulated area. The magnitude of the drawdown, about 9 cm, is close to that predicted by a previous estimation (10 cm) and would be adequate for efficient removal of perched water from the root zone. It is important to note that the coefficient values used in this calculation represent realistic values for an actual putting green situation and for a capillary drain material.

As previously described, the exemplary embodiment of the present invention utilizes fiberglass rope as the material for accomplishing capillary drainage. There are, however, a variety of materials that may serve as capillary drain. Quite similar to fiberglass rope is fiberglass tape, a weaving of fiberglass strands having a rectangular cross-section. A material

substantially different from fiberglass rope is a contained column of sand or other mineral particles. This contained column may consist of a tubular netted mesh filled with appropriately sized sand particles. Both of these alternative materials are (i) wetable; (ii) contain a distribution of pore sizes that are compatible with the root zone; (iii) have an adequate flow capacity to allow timely removal of perched water, and (iv) have a structural integrity that would resist free water flow.

There are presently about 267,000 putting greens in the U.S. with 70-90% of these greens utilizing a layered soil profile as described above. Presumably, the methods utilized for installing capillary drains into existing putting greens can be used for newly constructed greens. The specific installation approach typically depends on whether the capillary drain has a circular cross-section, as in a fiberglass rope, or a rectangular cross-section as in a fiberglass tape.

In the case of a circular cross-section capillary drain, installation is a two-step procedure. First, a pilot hole is created in the soil extending from the surface to the maximum depth of drain insertion. Subsequently, the capillary drain material is inserted into the pilot hole. As the pilot hole needs to extend through both the sandy root zone and a layer of fine gravel, it is desirable to employ a solid, pointed tip, circular diameter tine to create the pilot hole of a diameter slightly larger than the capillary drain. A mechanical actuator such as a hydraulic ram, for example, is used to drive the tine vertically into the soil and remove it leaving a pilot hole. To facilitate insertion of a flexible capillary drain (such as a fiberglass rope) to the desired depth, some added stiffening support may be required. Inserting and affixing a small diameter wire, plastic or wooden dowel into the center and along the long axis of the rope provides this stiffening support. The modified section of fiberglass rope is then be inserted to the desired depth. The resultant cavity extending from the soil surface to upper surface of the capillary drain is then backfilled with appropriate root zone material.

Installation of a fiberglass tape capillary drain is a one-step procedure because a pilot hole is not typically needed. A section of fiberglass tape, lying flat and extended over the soil surface is driven directly into the soil to the appropriate depth by a thin but reinforced metal plate. The section of tape (c.a. 2-inch wide by 0.125-inch thick) is typically twice the length of the final vertical extension of the drain and has affixed in the center a narrow protective

band. The tape is centered in a channel having a slot in the bottom that subsequently rests on, or is supported just above, the soil surface. The slot in the channel is positioned over the point of insertion. The reinforced metal plate is slightly wider than the tape and has a length corresponding to the maximum depth of insertion. The metal plate is positioned over the center of the tape and correspondingly the slot in the channel. Again, using a mechanical actuator, the metal plate is driven vertically, intercepting the protected center of the tape, and inserting the capillary drain into the soil. In this case, the capillary drain is a doubled section of fiberglass tape and only a small scar remains visible on the soil surface.

The installation methods described above may also include mechanization of the insertion process so that a single operator of a small, motorized unit could, in a timely fashion, install an array of drains within a green.

This invention is intended primarily for supplemental drainage of a soil profile that consists of a sandy root zone placed over fine gravel. Other forms of soil layering may be found in turf soil profiles and many of these layered systems may be in need of supplemental drainage. For example, consider a sandy root zone placed within an excavation into a fine textured soil and containing conventional, spaced-apart drainage pipe. Conceivably, this system may also benefit from supplemental drainage in some form because the low permeability of the fine textured soil inhibits the natural downward flow of water, leading to an accumulation or perching of water in the sandy root zone. A passive capillary drainage system in this case would extend from the lower reaches of the sandy root zone to a relief point below the interface between the two layers.

Thus, a capillary pathway would be established to provide the supplemental drainage. The relief point, in this case, may be a spaced-apart drainage pipe trench excavated into the fine textured subsoil. The individual elements of the capillary drain may then be angled to both intercept the trench and contain sufficient vertical drop from the inflow to the outflow ends. Finally, the capillary drain should have structural integrity resisting the erosive action of freely flowing water that would occur near the lower reaches of the drain.

The essential components of a soil profile that would need supplemental drainage and may benefit from passive capillary drainage are as follows: (i) a distinct layering of soil materials that is oriented approximately perpendicular to the gravitational gradient; (ii) a

composition of these layers such that capillary water flow is inhibited at the interface; due to either the capillary break phenomena of a sandy root zone placed over gravel, or the permeability reduction of a sandy root zone placed over a fine textured soil; (iii) a surface layer that has a sandy texture or otherwise sufficient permeability to allow, in a timely fashion, the lateral migration of water to reasonably spaced-apart capillary drains; (iv) a free water collection volume or conveyance located adjacent to the lowest elevation end of the capillary drain; (v) the need for or desire to employ a capillary drainage material that exhibits structural integrity.

This invention may also be utilized with soils supporting plants other than turfgrass. The essential components are not dependent on the specific plant being grown, with the recognition that recreational turf is often grown in a sandy root zone. Thus, this invention may be applied to situations ranging from the growth of horticultural crops to soil landfill covers.

While the above description contains much specificity, this should not be construed as a limitation on the scope of the invention, but rather as an exemplification of certain preferred or exemplary embodiments. Numerous other variations of the present invention are possible, and it is not intended herein to mention all of the possible equivalent forms or ramifications of this invention. Various changes may be made to the present invention without departing from the scope or spirit of the invention.